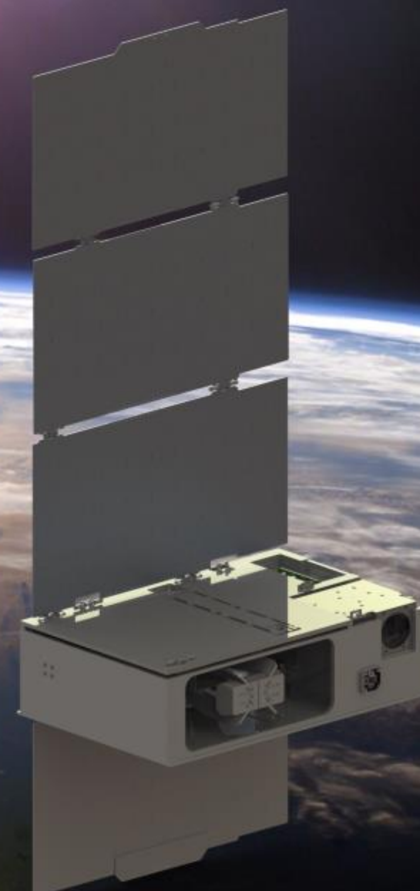
The Colorado Ultraviolet Transit Experiment (CUTE):

A cubesat to study the most extreme exoplanets



@CuteCubeSat

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

Kevin France – University of Colorado

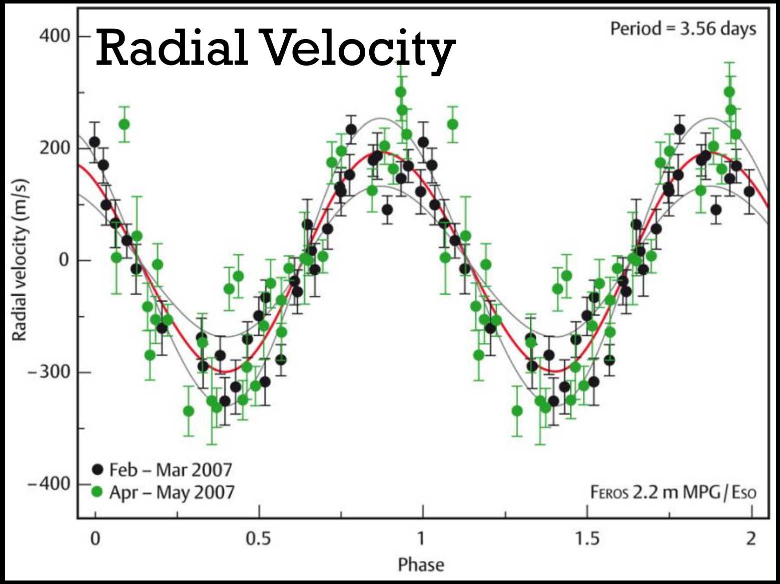
APAC Meeting, 15 March 2021

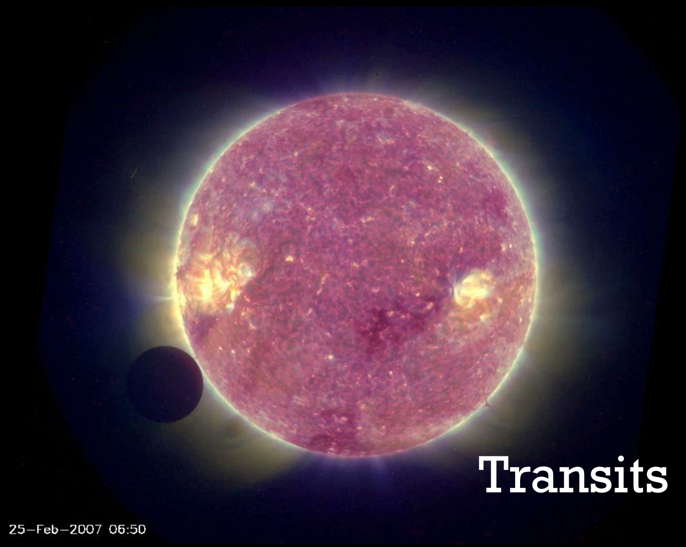
Extrasolar Planets:

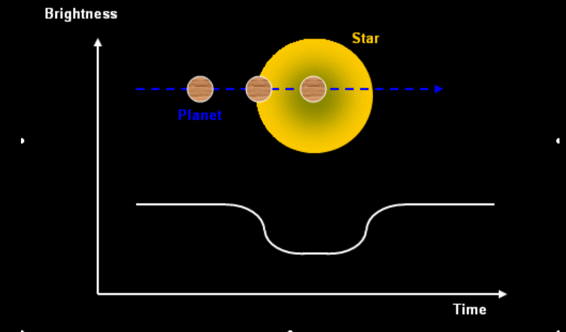
$N_{plan}(2021)$

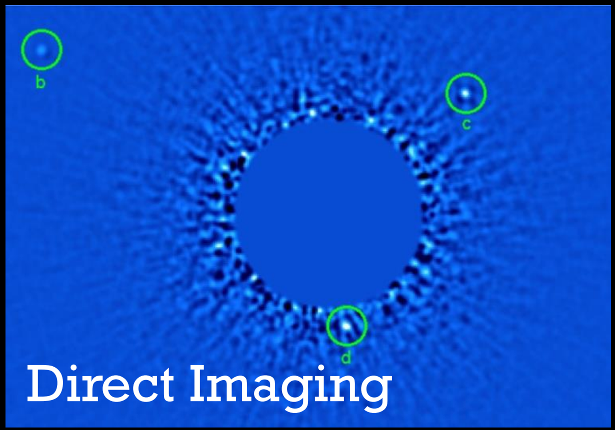
~4300 Confirmed

~$200 \times N_{plan}(1999)$



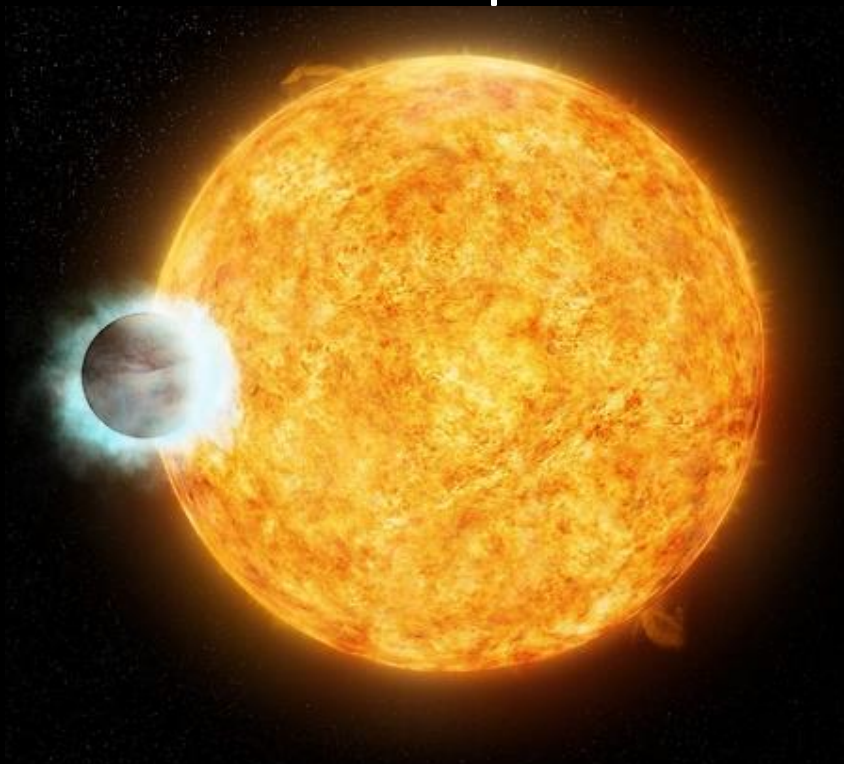






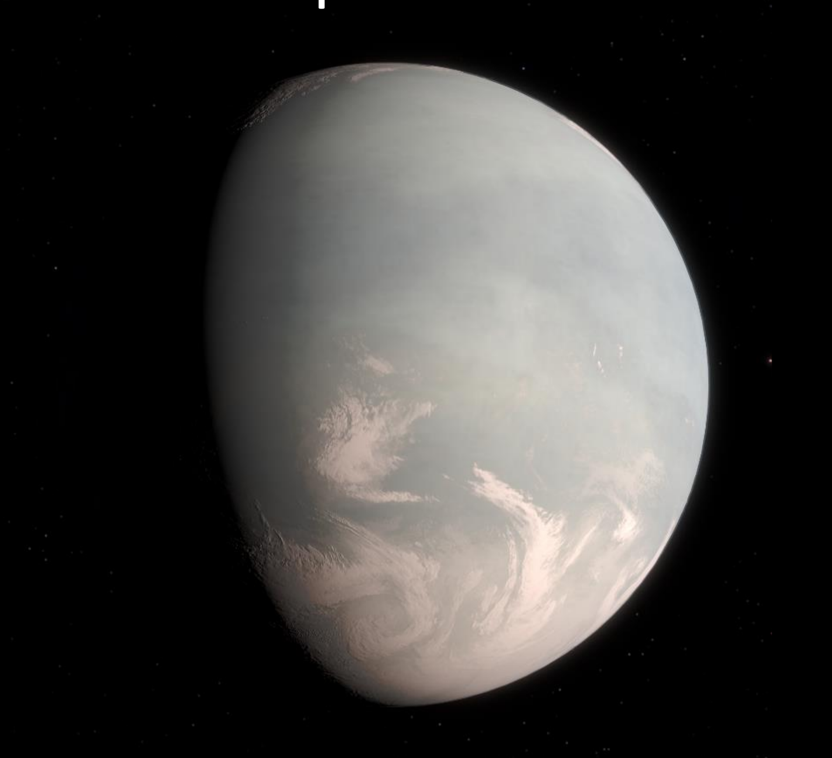
The Extrasolar Planet Zoo

Hot Jupiter



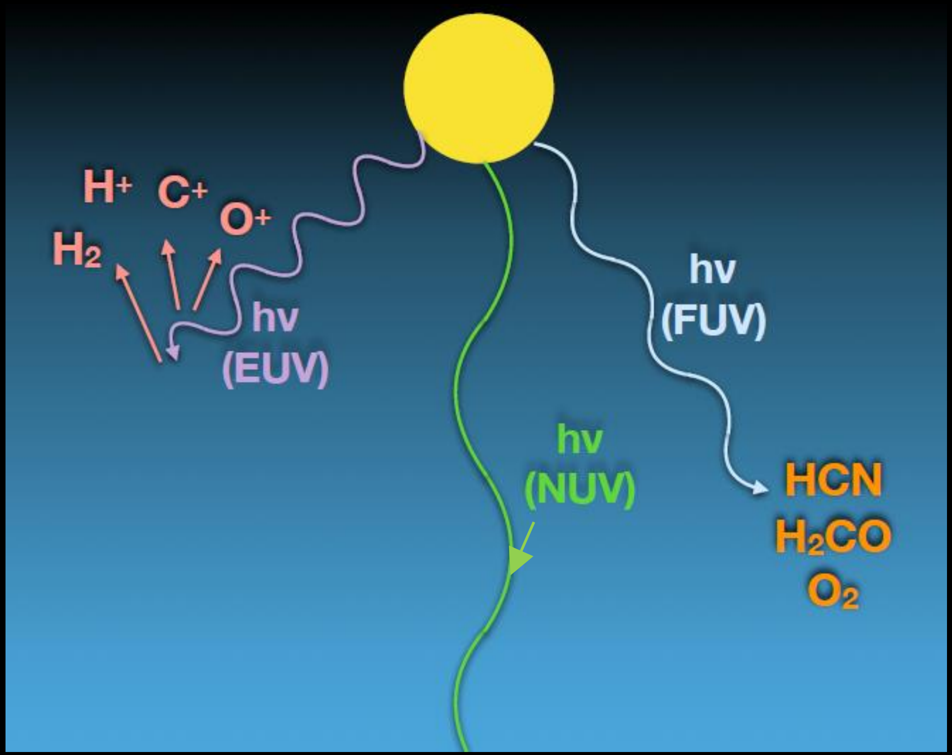
WASP-18b, solar-type host
M ~ 10 M_J, R ~ 1.1 R_J
a ~ 0.02 AU
T_{eff} ~ 2400 - 3100 K
(Hellier et al. 2009)

Super-Earth



GJ 832c, red dwarf host
M sin(i) ~ 5.2 M_E, R ~ 1.5 R_E
a ~ 0.16 AU
T_{eff} ~ 230 - 280 K
(Wittenmyer et al. 2014)

ATMOSPHERIC ESCAPE, NEAR AND FAR



- Escape alters ~all planetary atmospheres

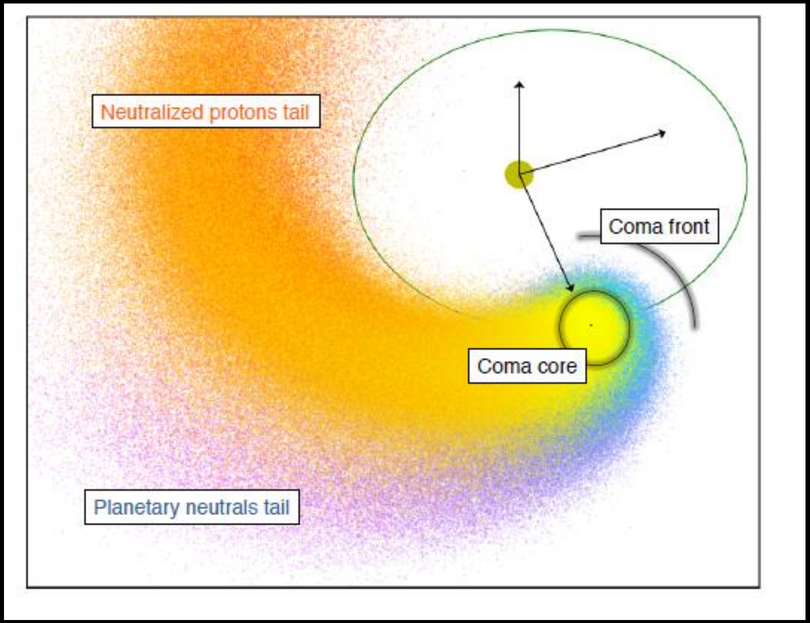
- The high-energy stellar emission dominates atmospheric photochemistry, ionization, and heating

- Exoplanets are laboratories for studying extreme mass loss that no longer operates in the solar system

Figure courtesy of
Paul Rimmer - Cambridge

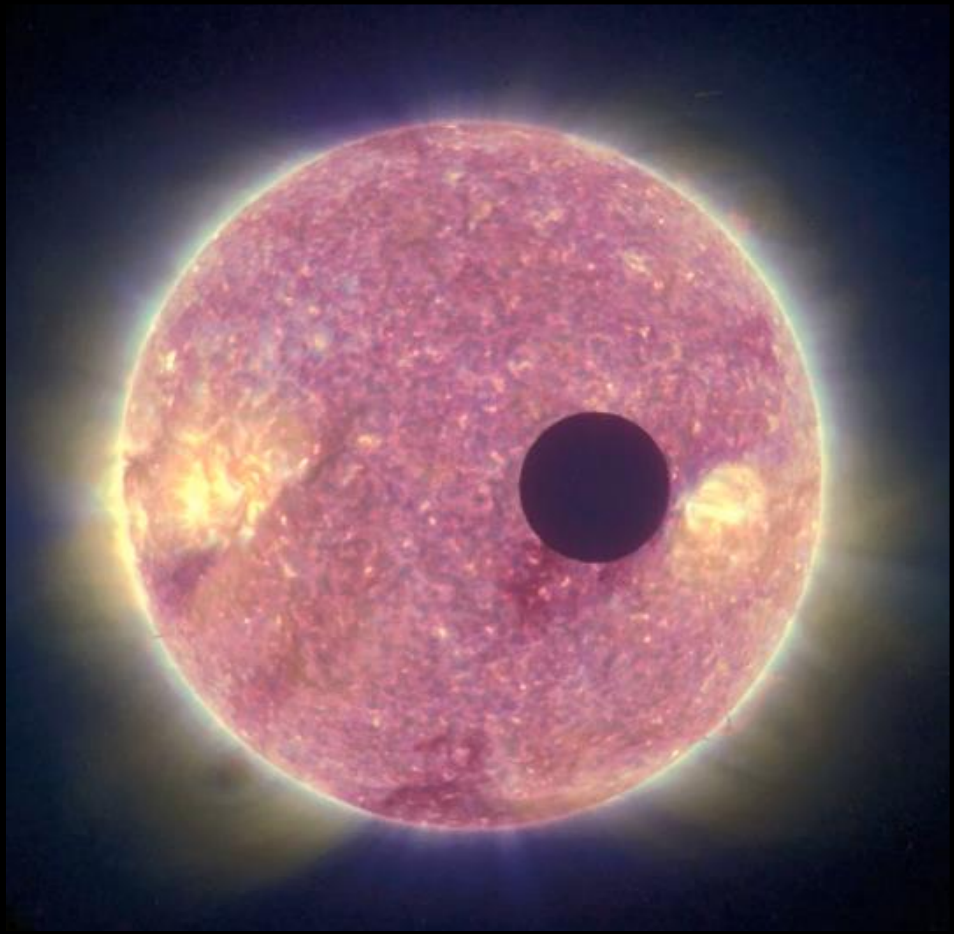
HOT JUPITER ATMOSPHERES

- **EUV heating driving mass-loss from short-period planets**
- Most spectacular example has been on the short-period Neptune-mass planet GJ 436b



EXOPLANET ATMOSPHERES

- Narrow-band/spectroscopic transit analysis can probe absorption by specific atmospheric constituents



Occultation Depth = $(R_P / R_*)^2$

EXOPLANET ATMOSPHERES

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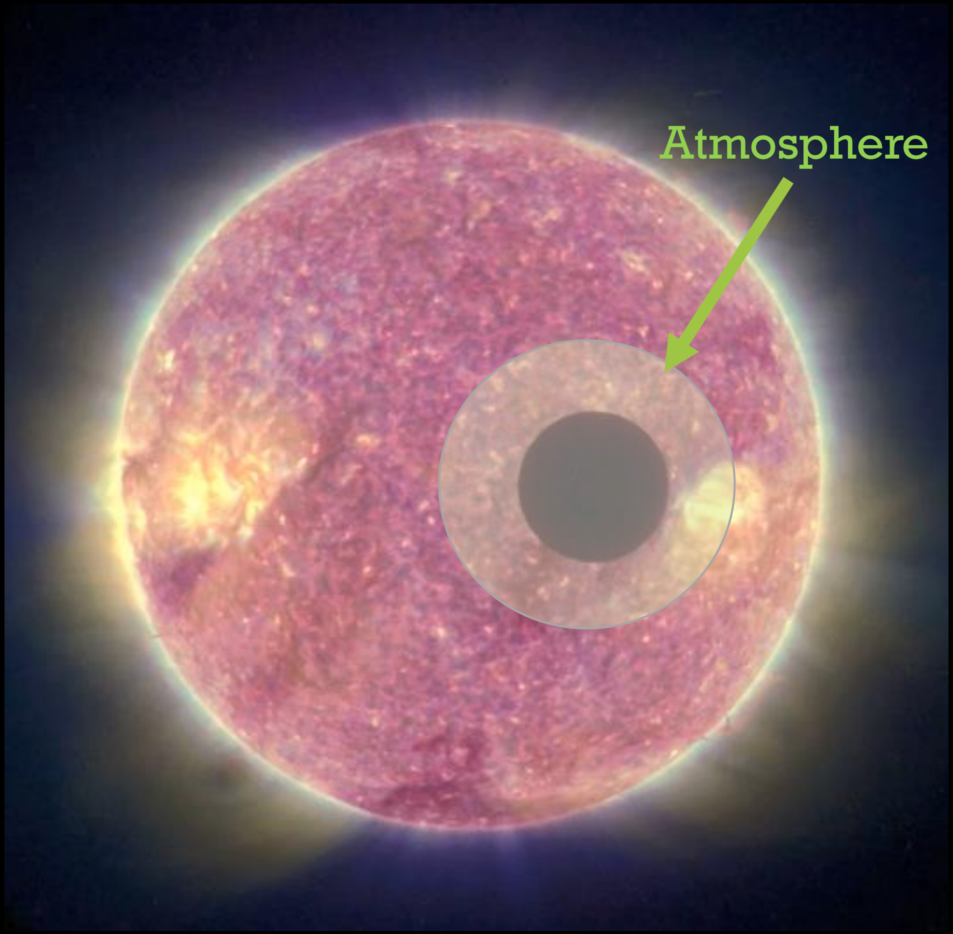

Occultation Depth = $(R_P(\lambda) / R_*)^2$

Transit Spectroscopy:
in-transit vs. out-of-transit

- Composition
- Temperature structure
- Velocity flows
- Mass-loss rates

Transit Spectroscopy of Short-period Planets

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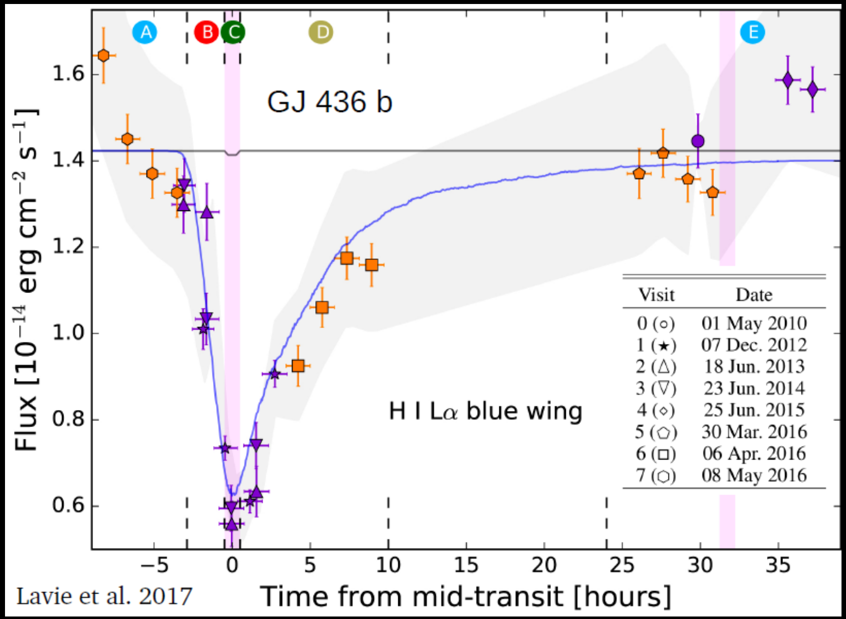
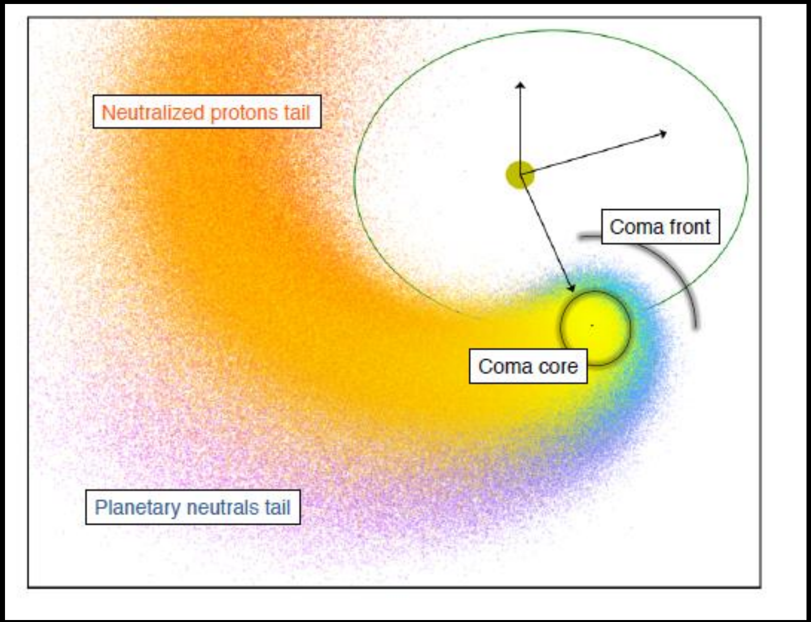




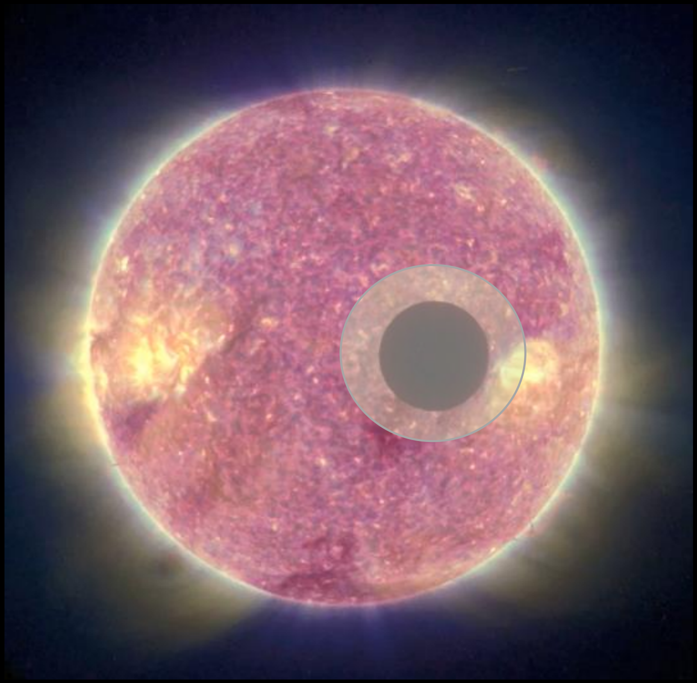
Hydrogen escaping from the upper atmosphere of GJ436b

(Kulow et al. 2014; Ehrenreich et al. 2015; Bourrier et al. 2016; Lavie et al. 2017)

Transit depth ~ 50% (!)

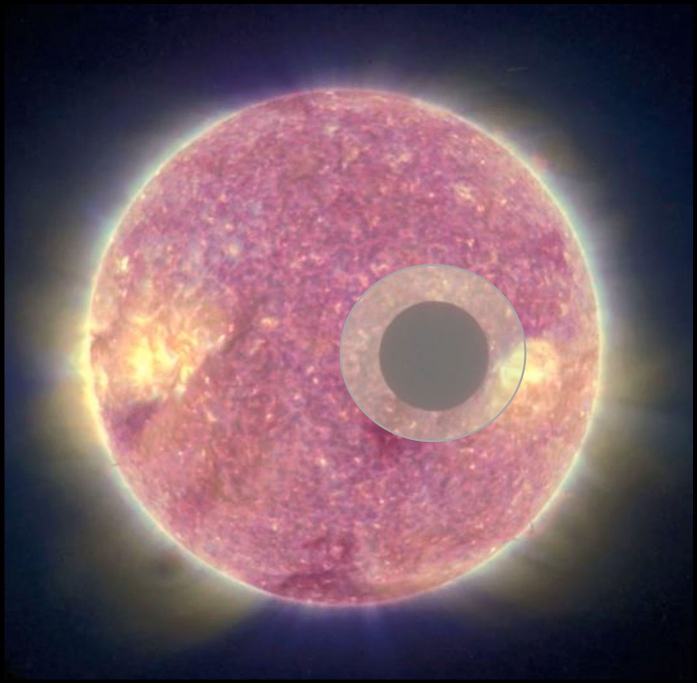
Extreme Exoplanet Atmospheres: challenges

- For the ~half-dozen Hot Jupiters measured with Hubble, we often find conflicting results, even on the same planet!



Extreme Exoplanet Atmospheres: challenges

- Often discrepant results: time-variability in the star(?), planetary mass-loss rate (?), or apples-vs-oranges observations and data reduction algorithms



Extreme Exoplanet Atmospheres: challenges

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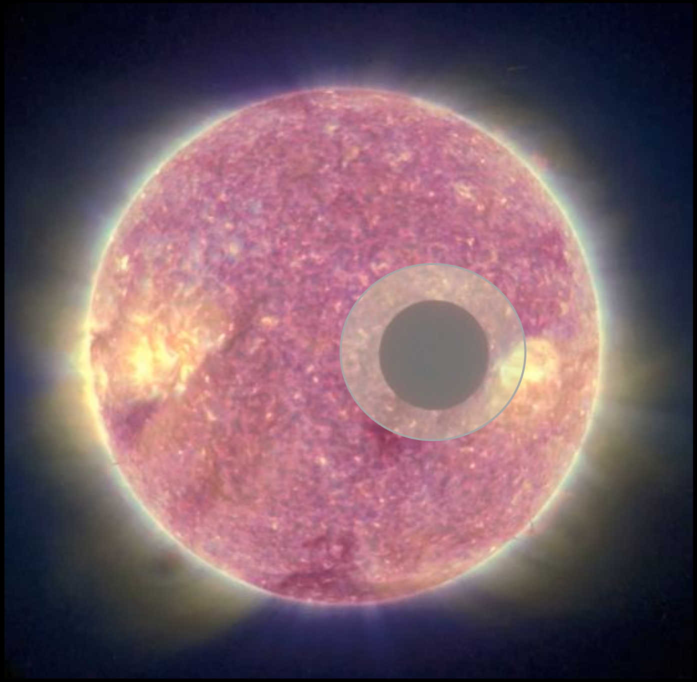
- Sample size of mass-loss measurements ~6, early-ingress ~1, late-egress ~2



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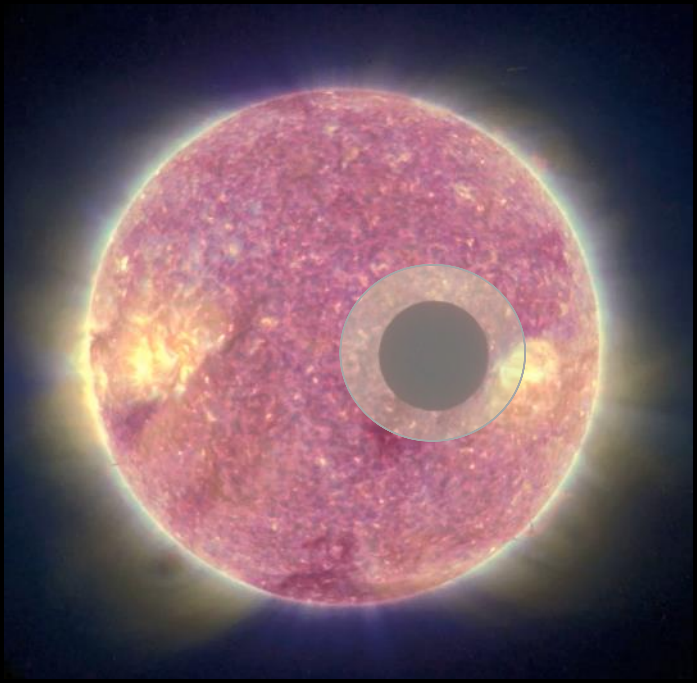
- Stellar baseline for transit measurements



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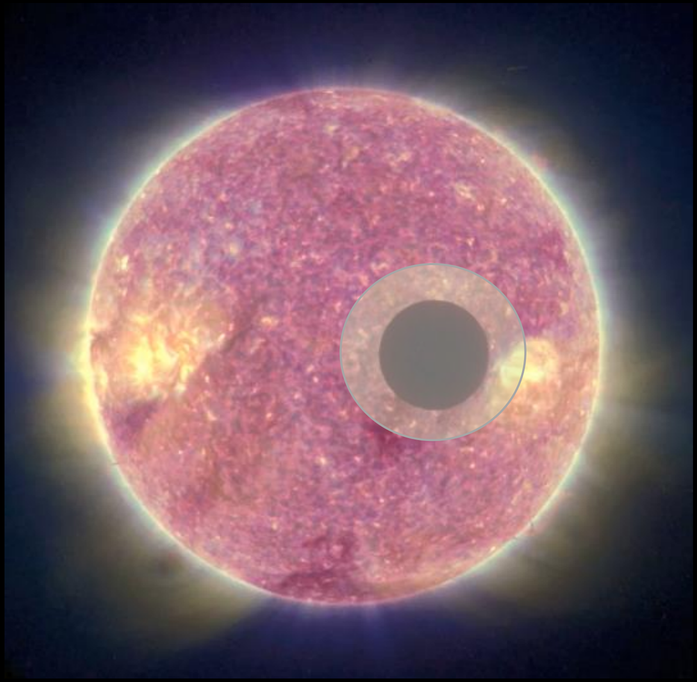

Extreme Exoplanet Atmospheres: challenges

- Often discrepant results: time-variability in the star(?), planetary mass-loss rate (?), or apples-vs-oranges observations and data reduction algorithms

  → multiple, consecutive transits, single data pipeline

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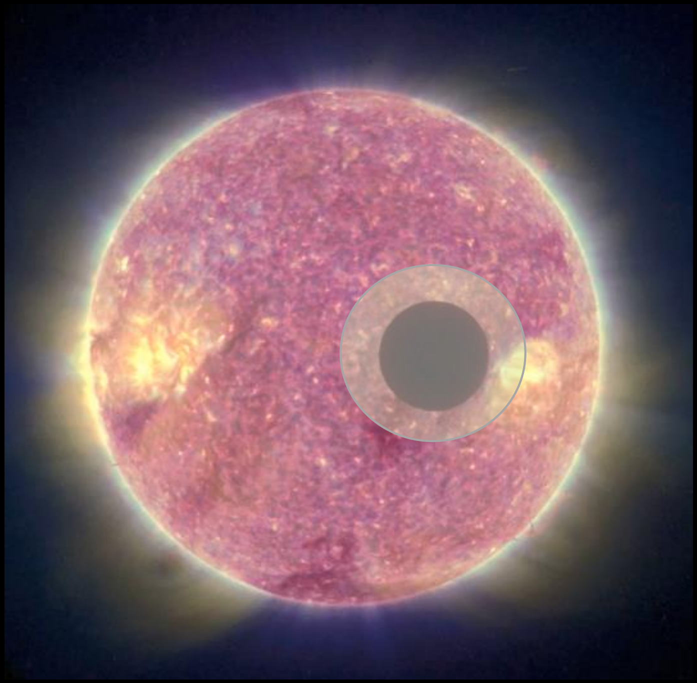

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Extreme Exoplanet Atmospheres: challenges

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  → **dedicated platform = more data**

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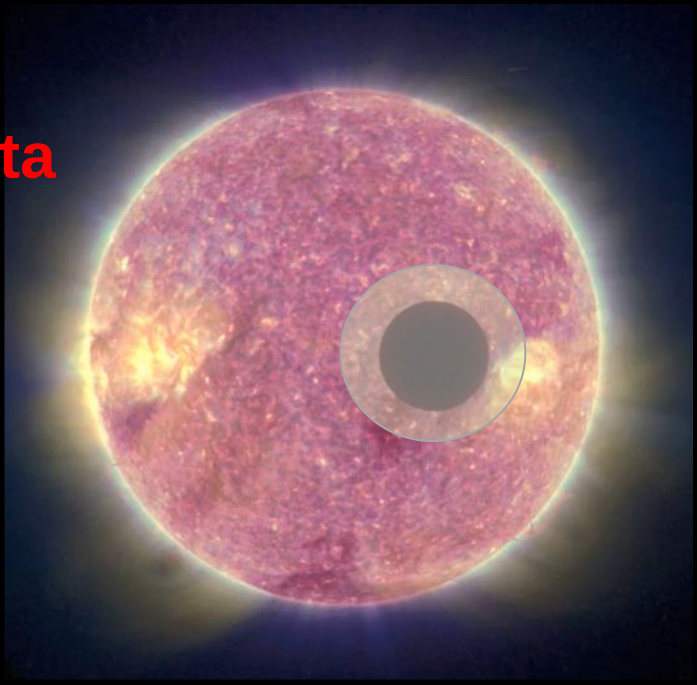

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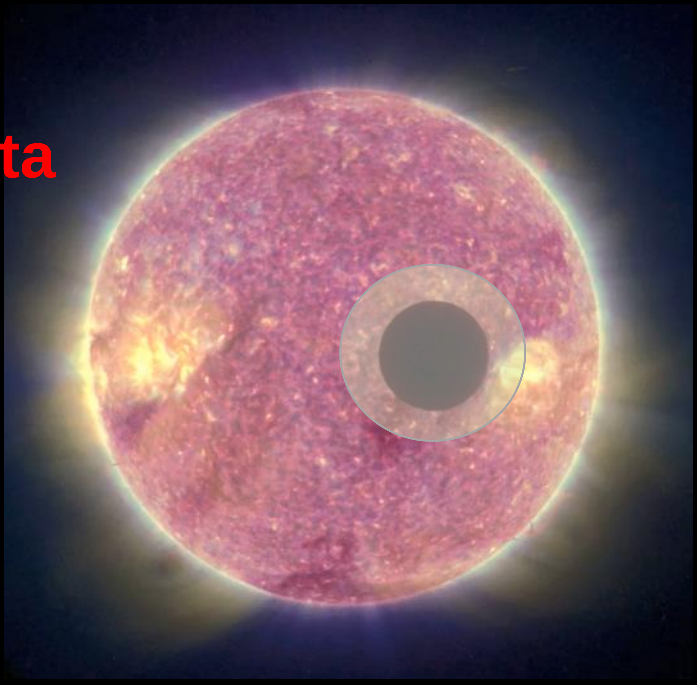

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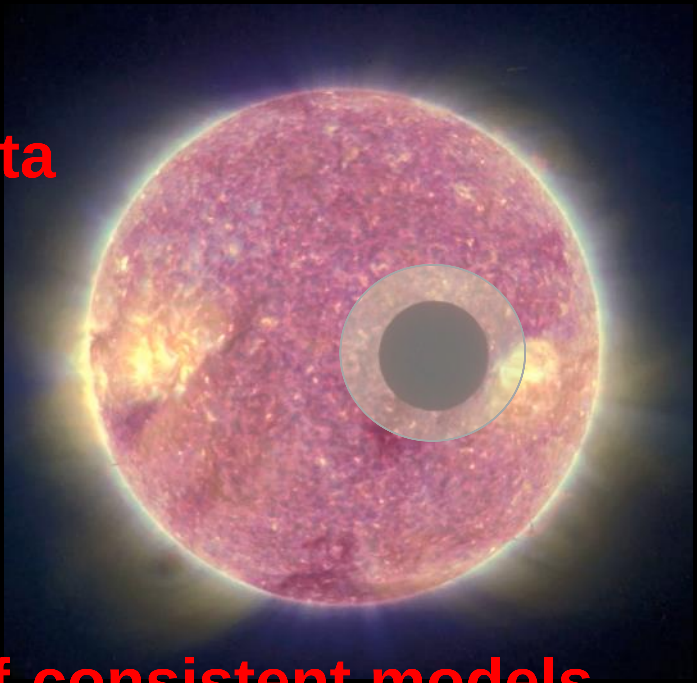
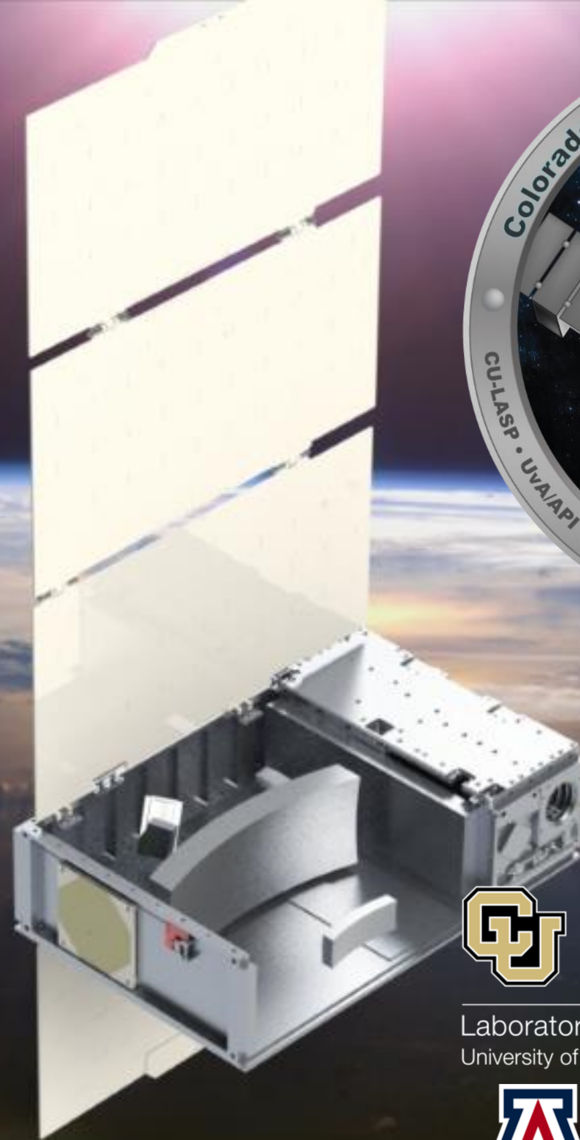
- Self-consistent modeling framework

  → **state-of-the-art, physically self-consistent models**



Colorado Ultraviolet Transit Experiment (CUTE)



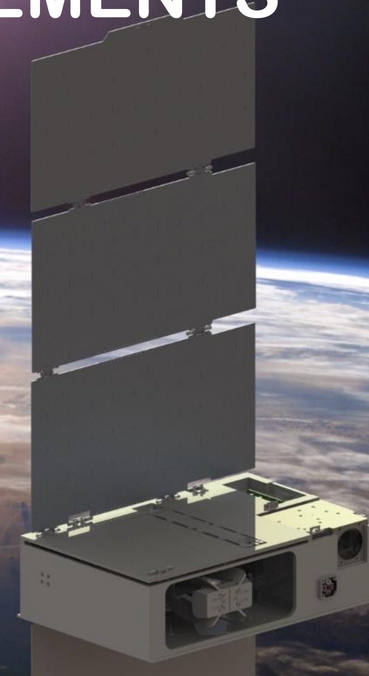
University of Colorado:
Kevin France (PI), Brian Fleming (PS), Arika Egan, Rick Kohnert (PM), Nicholas Nell, Stefan Ulrich, Nick DeCicco, Ambily Suresh, Wilson Cauley

United States:
Tommi Koskinen (UofA), Matthew Beasley (SwRI), Keri Hoadley (Caltech/Iowa)

Europe:
Jean-Michel Desert (Amsterdam), Luca Fossati (ÖAW), Pascal Petit (UdeT), Aline Vidotto (TCD)

Laboratory for Atmospheric and Space Physics
University of Colorado **Boulder**

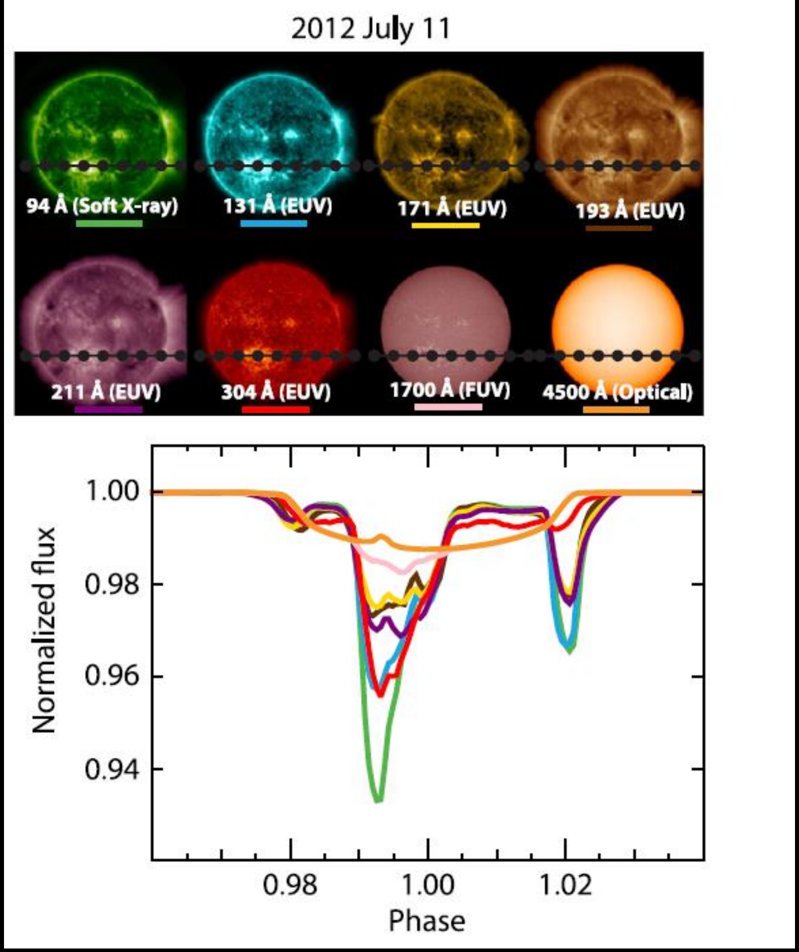
CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS



Survey of ~12-24 short-period transiting planets around nearby stars:

1) Atmospheric mass-loss rates
2) Escaping atmosphere composition

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

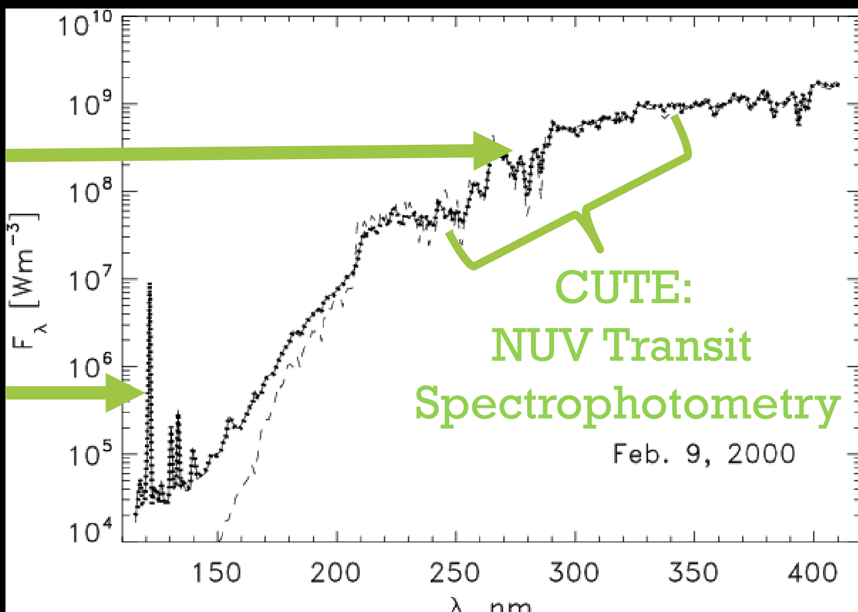


Llama & Shkolnik 2015, 2016

- **Most detections** of atmospheric mass loss have been carried out in the **FUV, Lyα** (e.g. Vidal-Madjar+ 2004, 2013, Linsky+ 2010, Ben-Jaffel+ 2007, 2013, Kulow+ 2014, Ehrenreich+ 2015, Bourrier et al. 2018)
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- **The NUV has a more uniform, mainly photospheric, intensity distribution**

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

Source: SDO



Krivova et al. 2006

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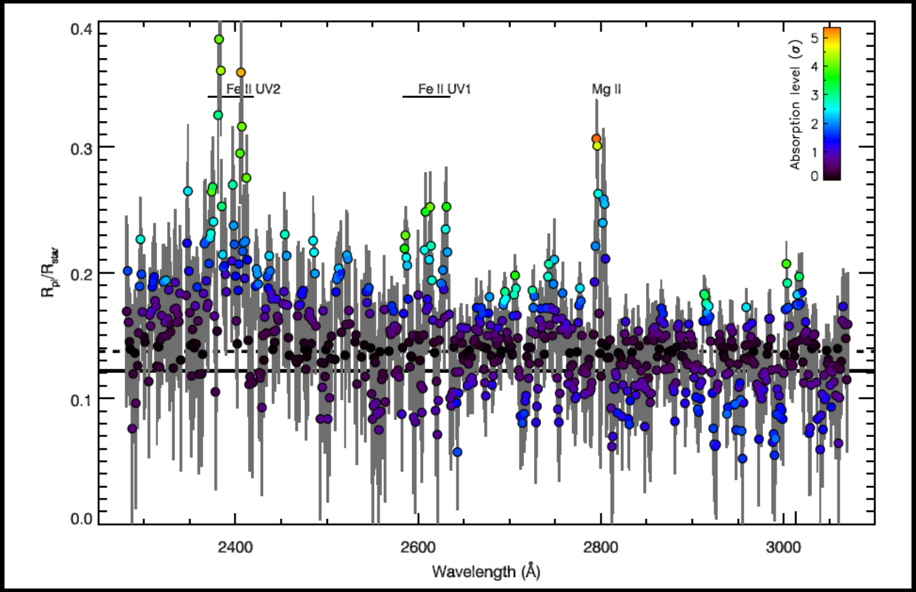
- Controversial interpretation due to low-S/N and uncertain chromospheric intensity distribution (e.g., Llama & Shkolnik 2015).
- The NUV has both a more uniform, mainly photospheric, intensity distribution AND an **overall brighter background for transit observations, ~50-1000x brighter.**

CUTE: A NEW APPROACH TO ATMOSPHERIC MASS-LOSS MEASUREMENTS

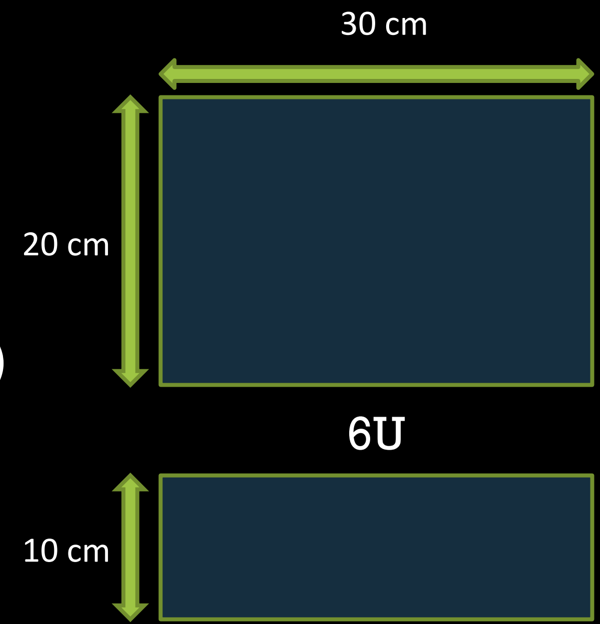


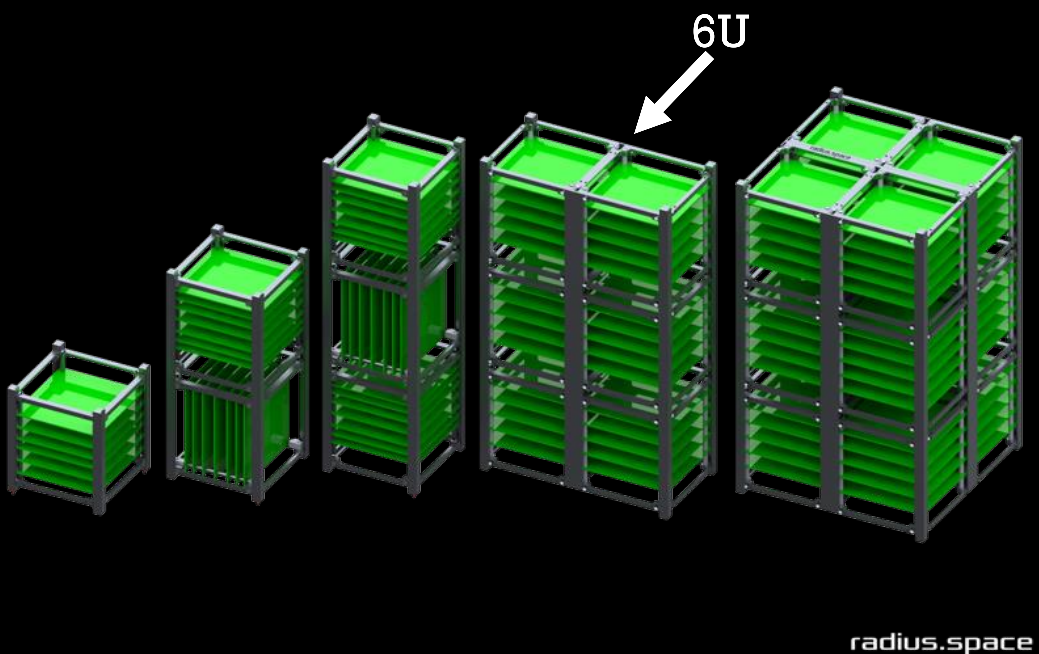
WASP-121b; Sing et al. 2019

- Brighter stellar flux enables spectroscopy in a correspondingly smaller platform
- <u>Spectroscopy</u> required to isolate escaping gas species

Astronomy with Cubesats: Dedicated Mission Architecture

- CUTE: First NASA grant funded UV/O/IR astronomy cubesat
  - Halosat X-ray cubesat (P. Kaaret, Univ. Iowa)
  - More widely used in Earth observing, education, and solar physics (e.g. CSSWE, MinXSS – Mason et al. 2017)





ASTERIA - JPL

France et al. (2020)

Astronomy with Cubesats: Dedicated Mission Architecture

CUTE:

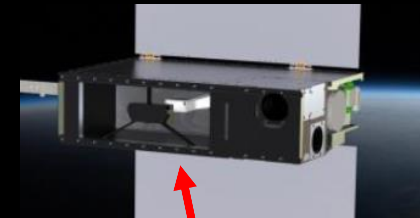
11.0 cm x 23.7cm x 36.2 cm

Family Size Cheerios available on Walmart.com:

7.8 cm x 23.9 cm x 34.4 cm

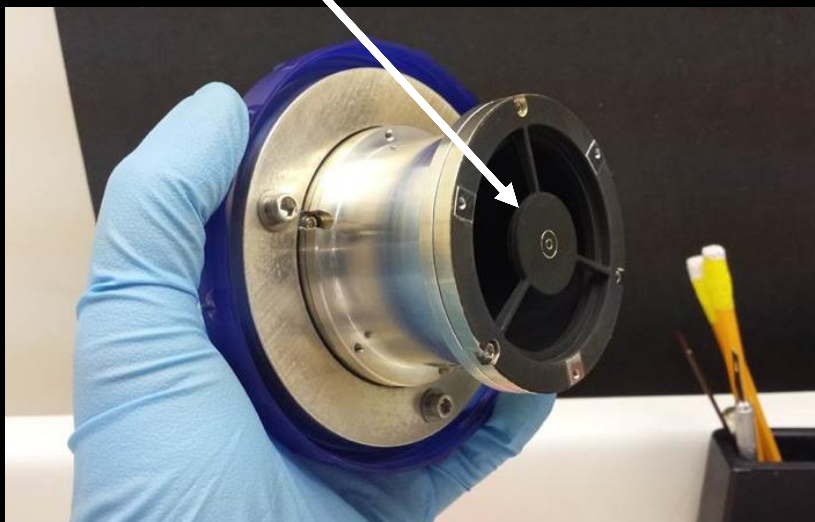
France et al. (2020)

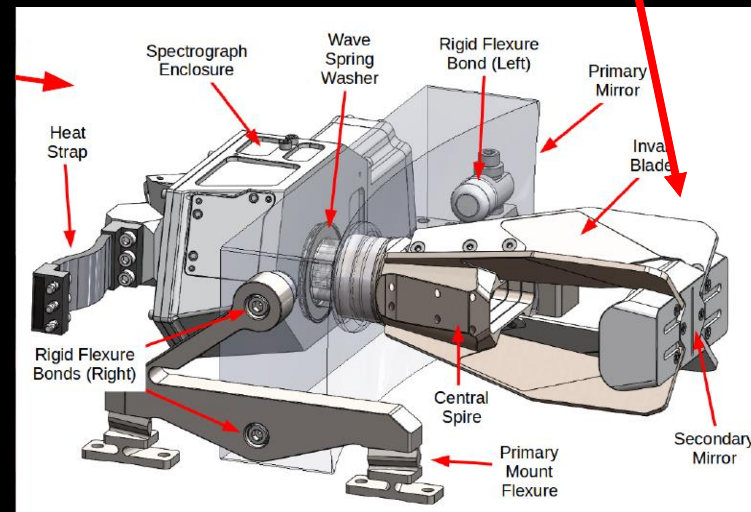
CUTE Telescope



Source: Nu-Tek Precision Optics

See CUTE design overview in Fleming et al. (2018)





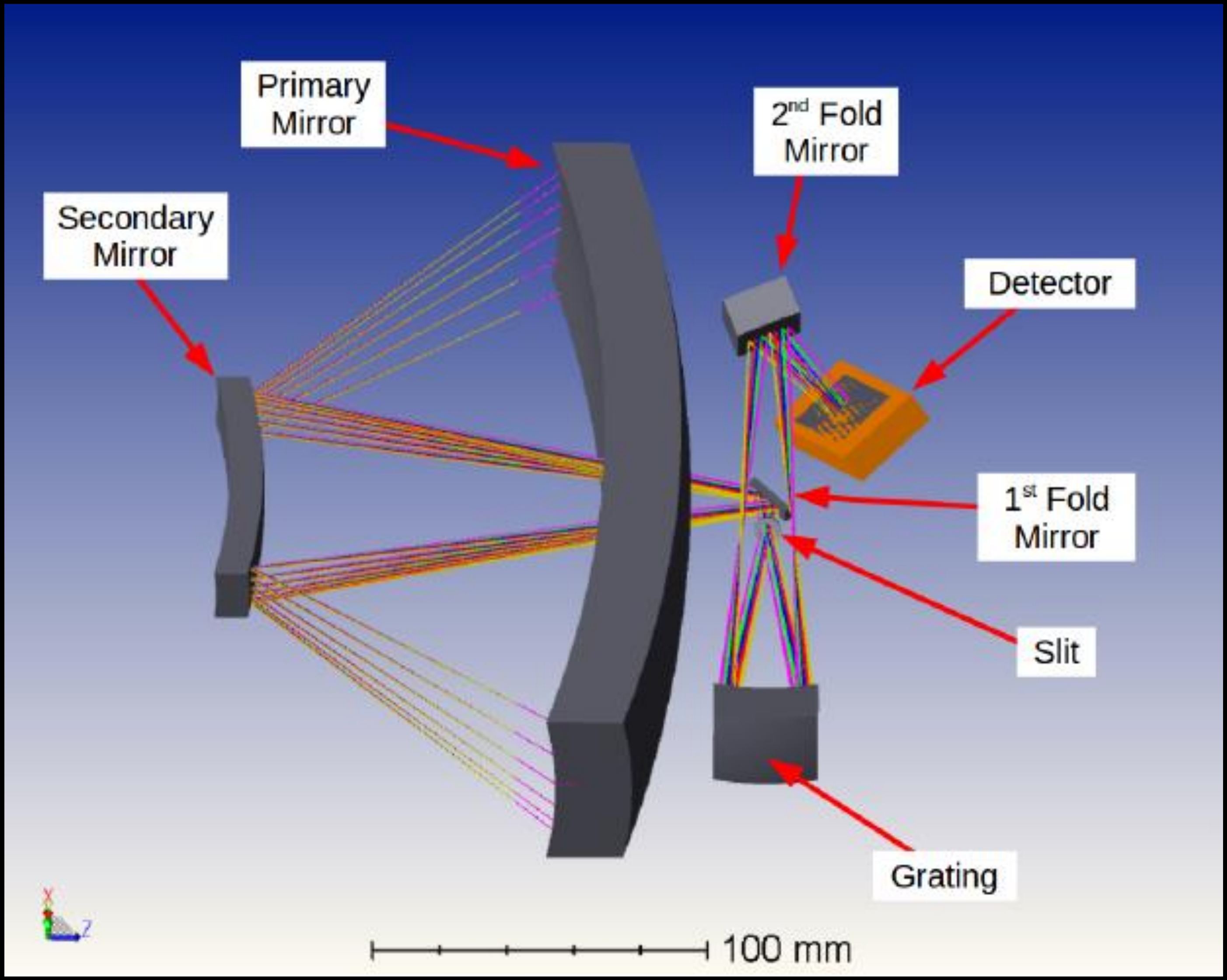
Geometric clear area for a 9cm Cassegrain: A_T ~ **47 cm^2**

Geometric clear area for a 20 x 8 cm Cassegrain: A_{CUTE} ~ **140 cm^2**

CUTE ~ **3 x** more collecting area

France et al. (2020), Egan et al. (2020)

CUTE Science Instrument



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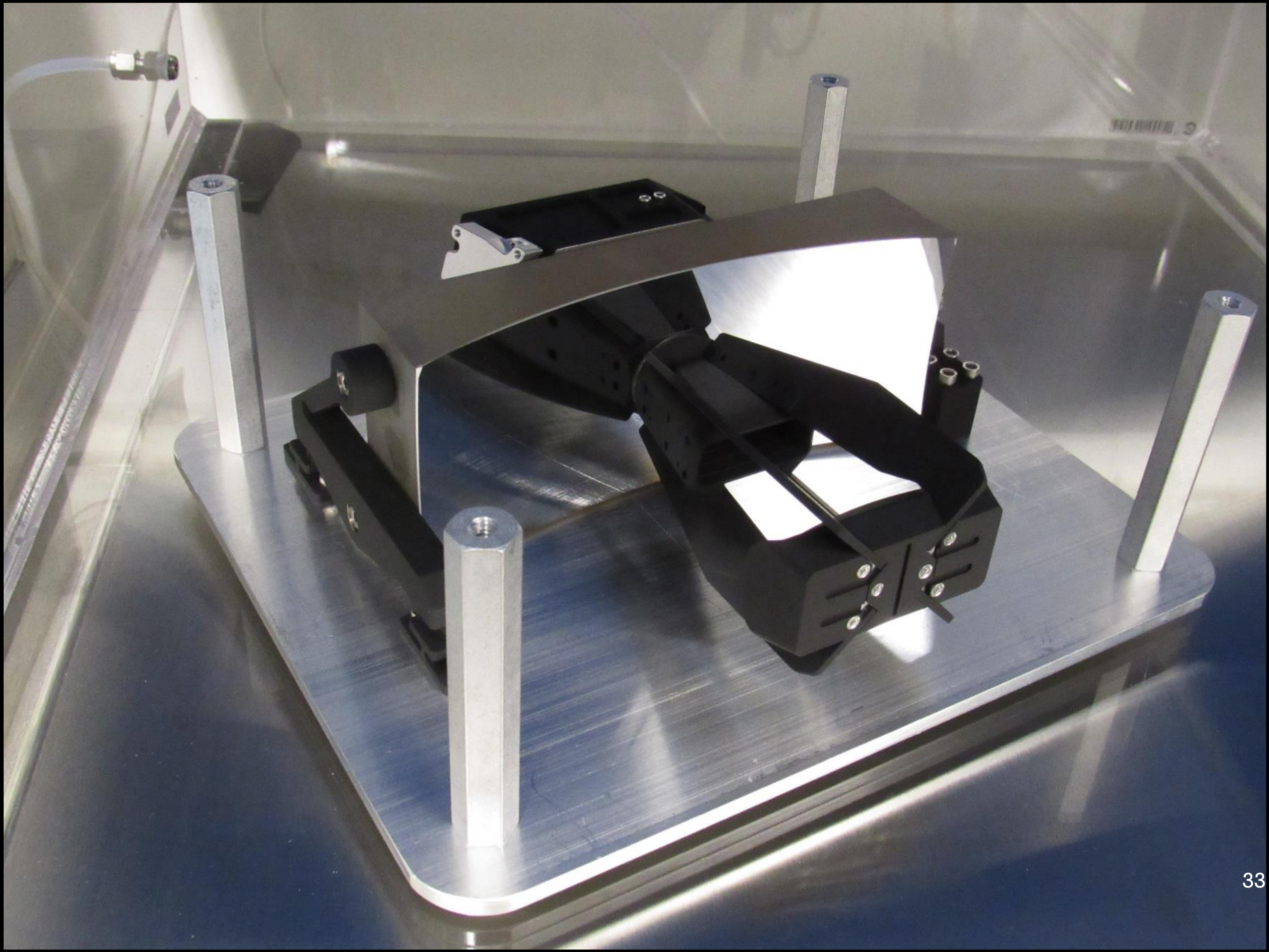
CUTE Telescope (Flight)



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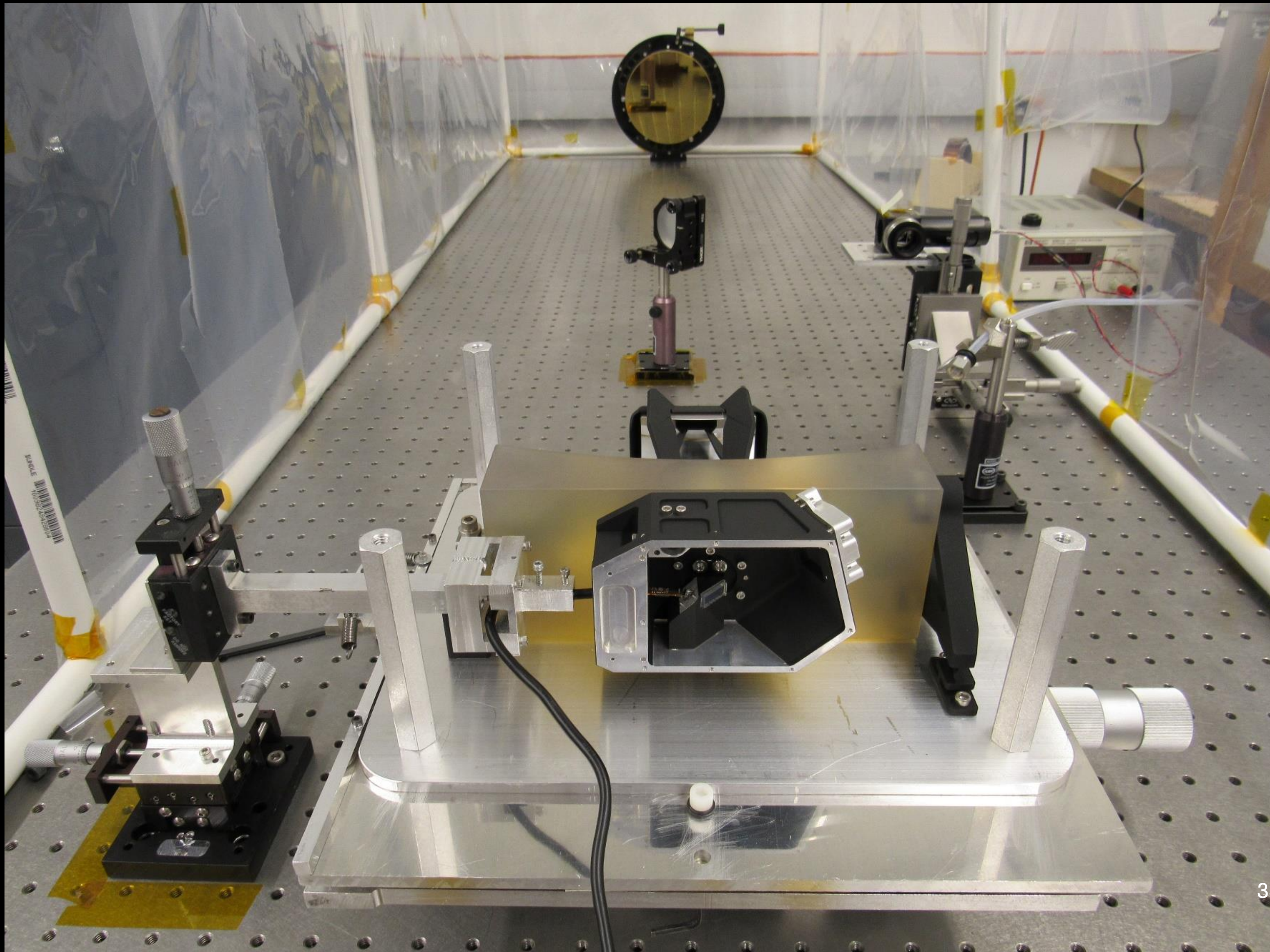

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CUTE Telescope (Flight)

See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

CUTE Operations: Student Ops Team

Student & PI Training Opportunities

Dr. Ambily Suresh

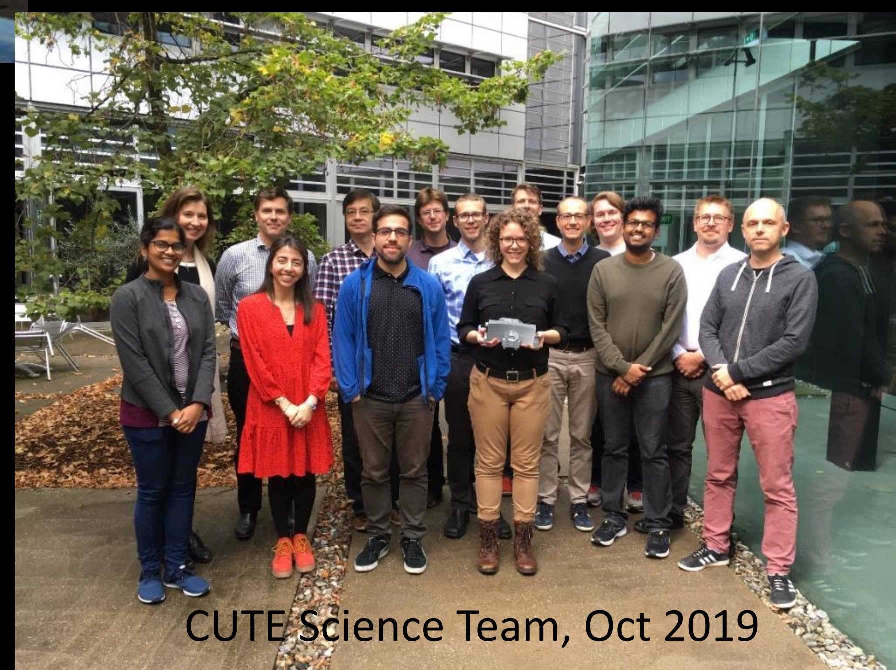
Arika Egan

Prof. Kevin France

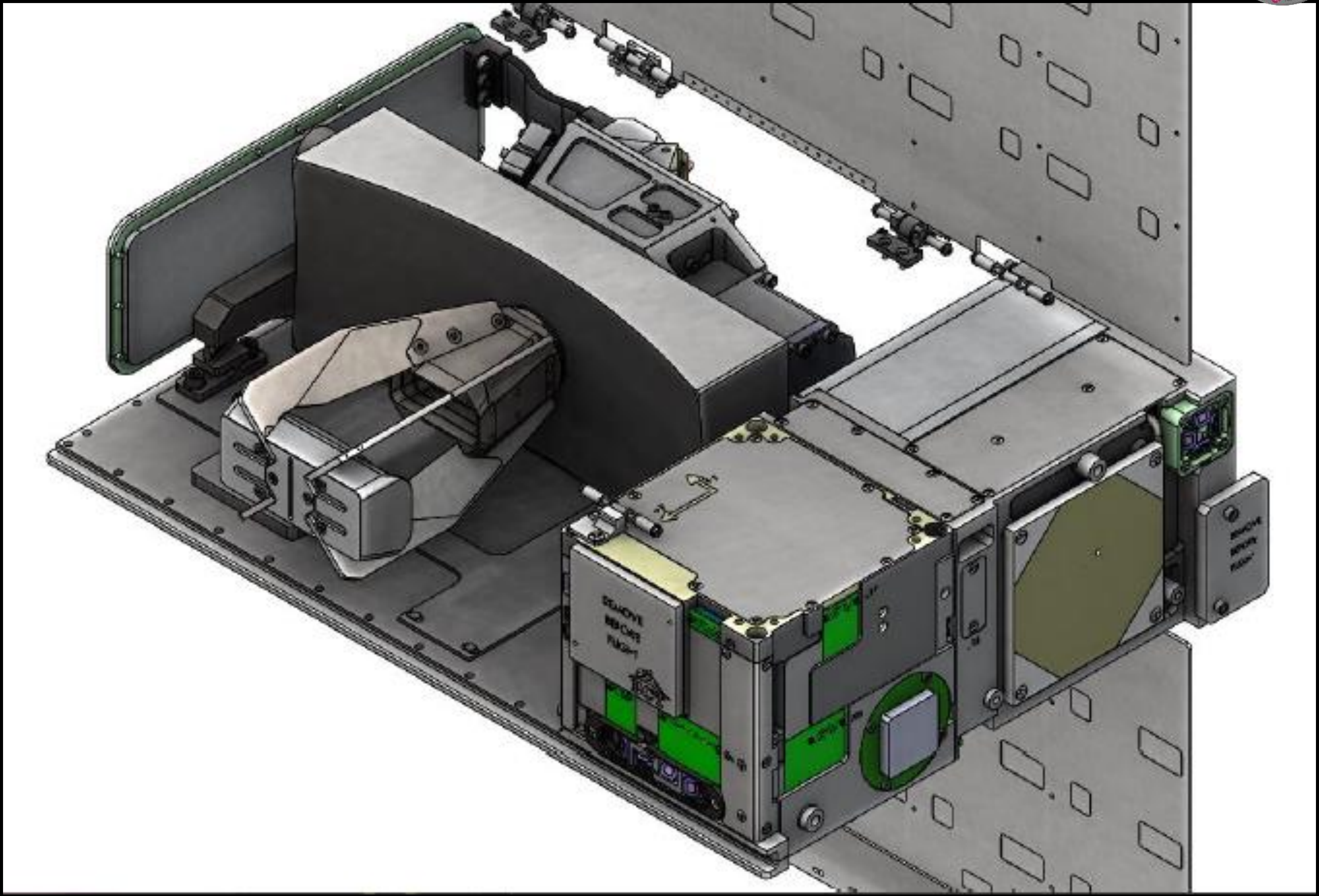
Stefan Ulrich

Nick DeCicco

Prof. Brian Fleming

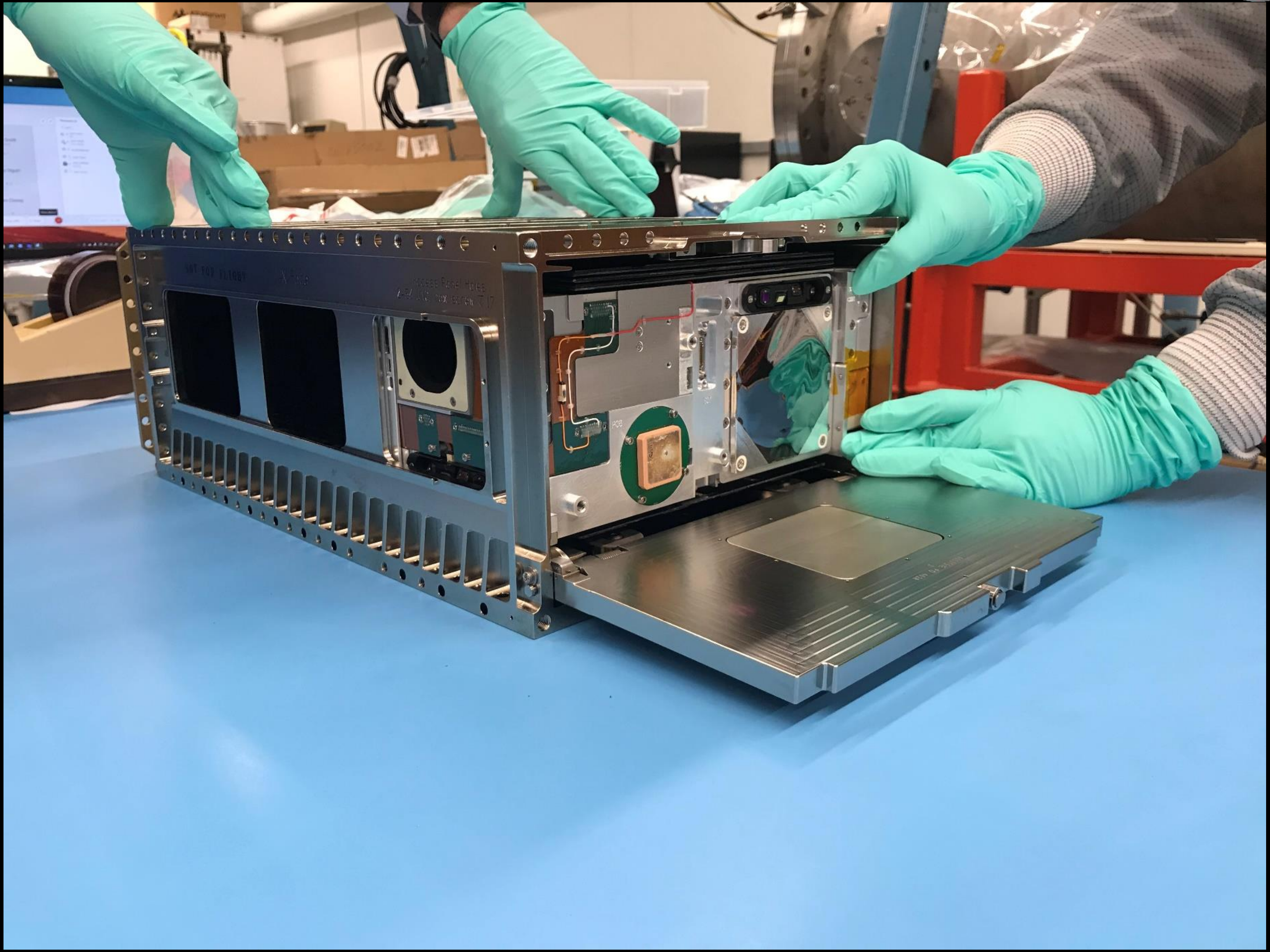


Integrated CUTE Science Instrument



See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

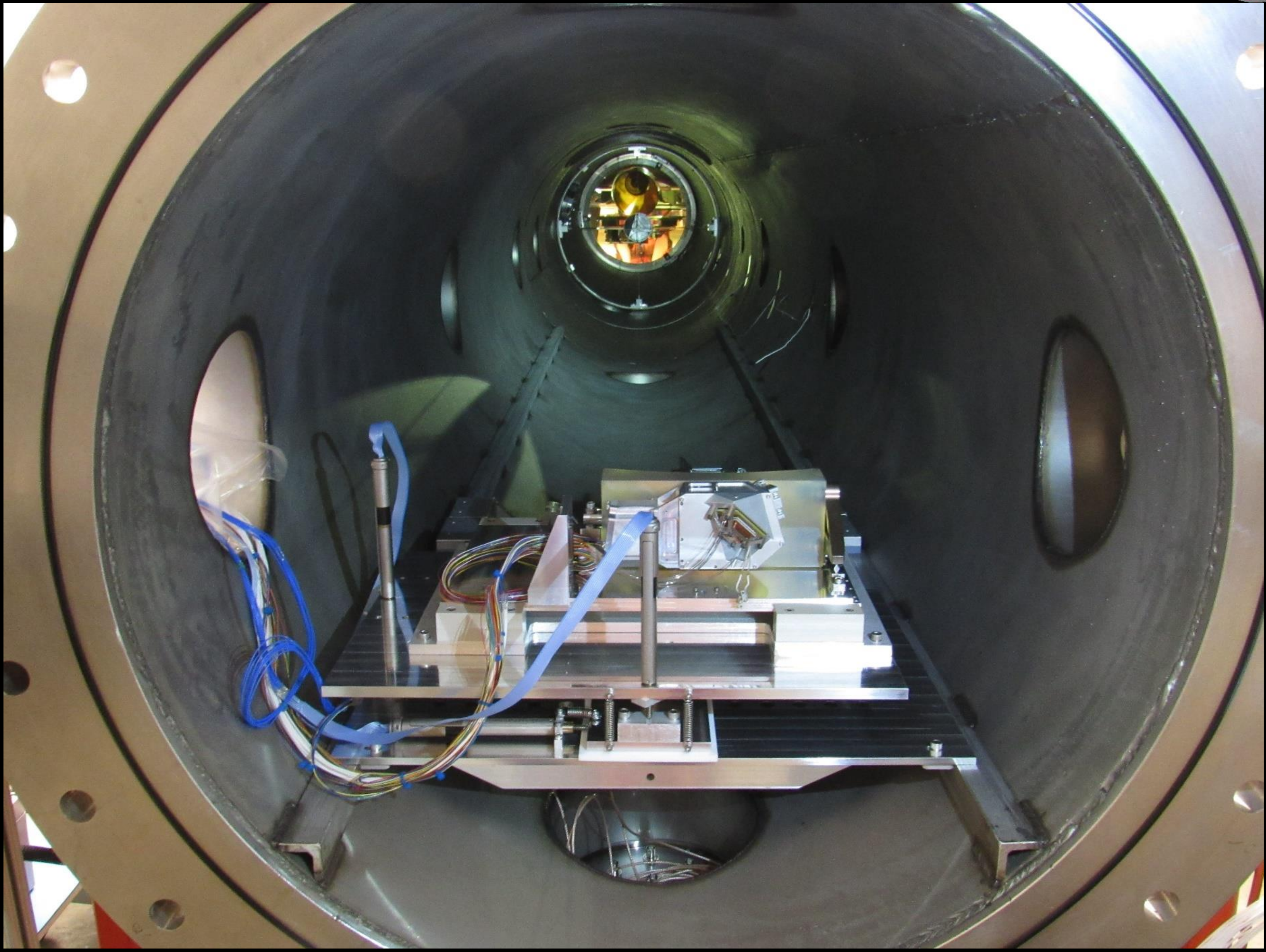
CUTE Spacecraft: Blue Canyon Technology



CUTE Spacecraft Testing

See CUTE design overview in Fleming et al. (2018); Egan et al. (2018)

CUTE End-to-End Testing



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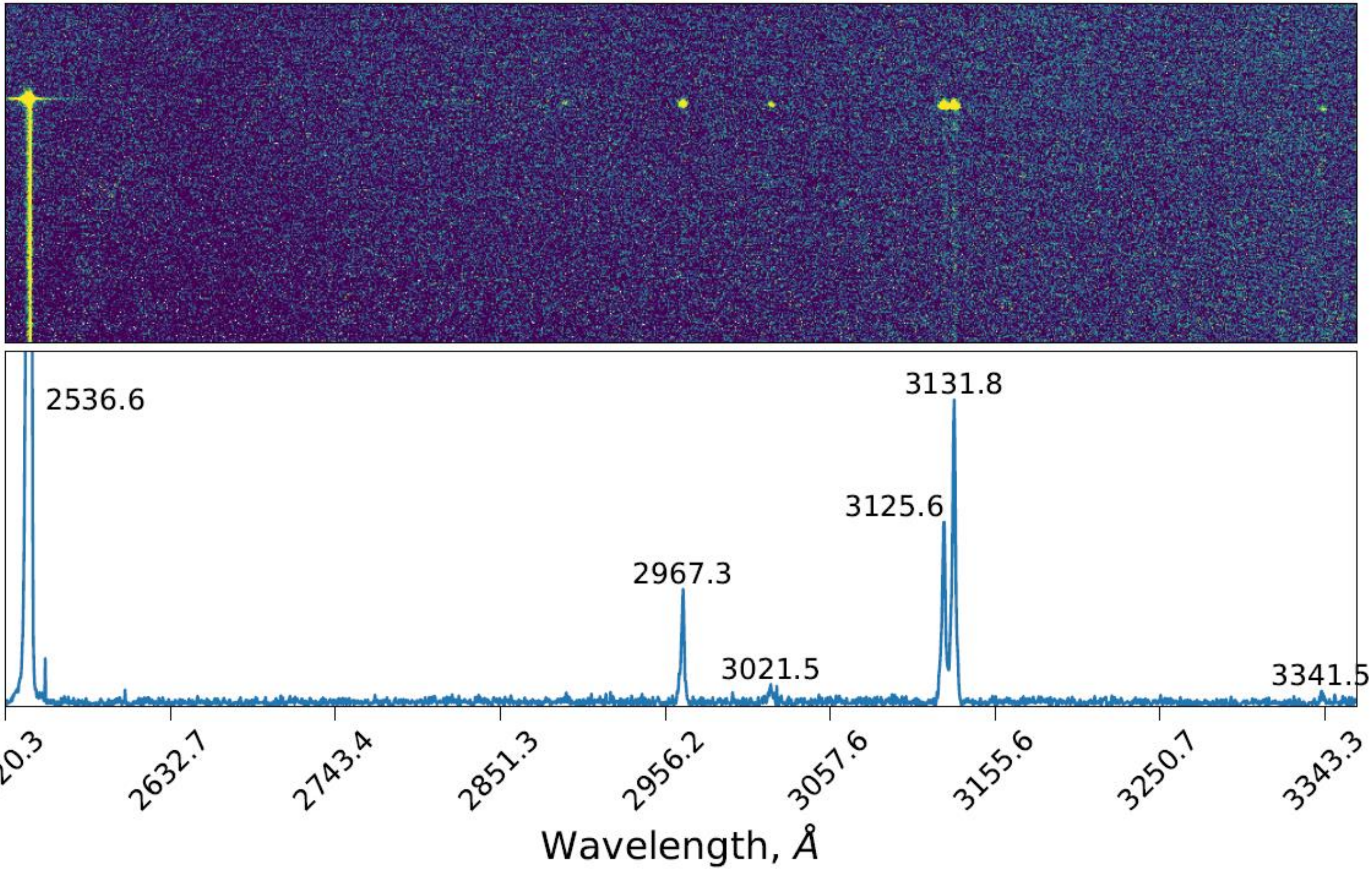
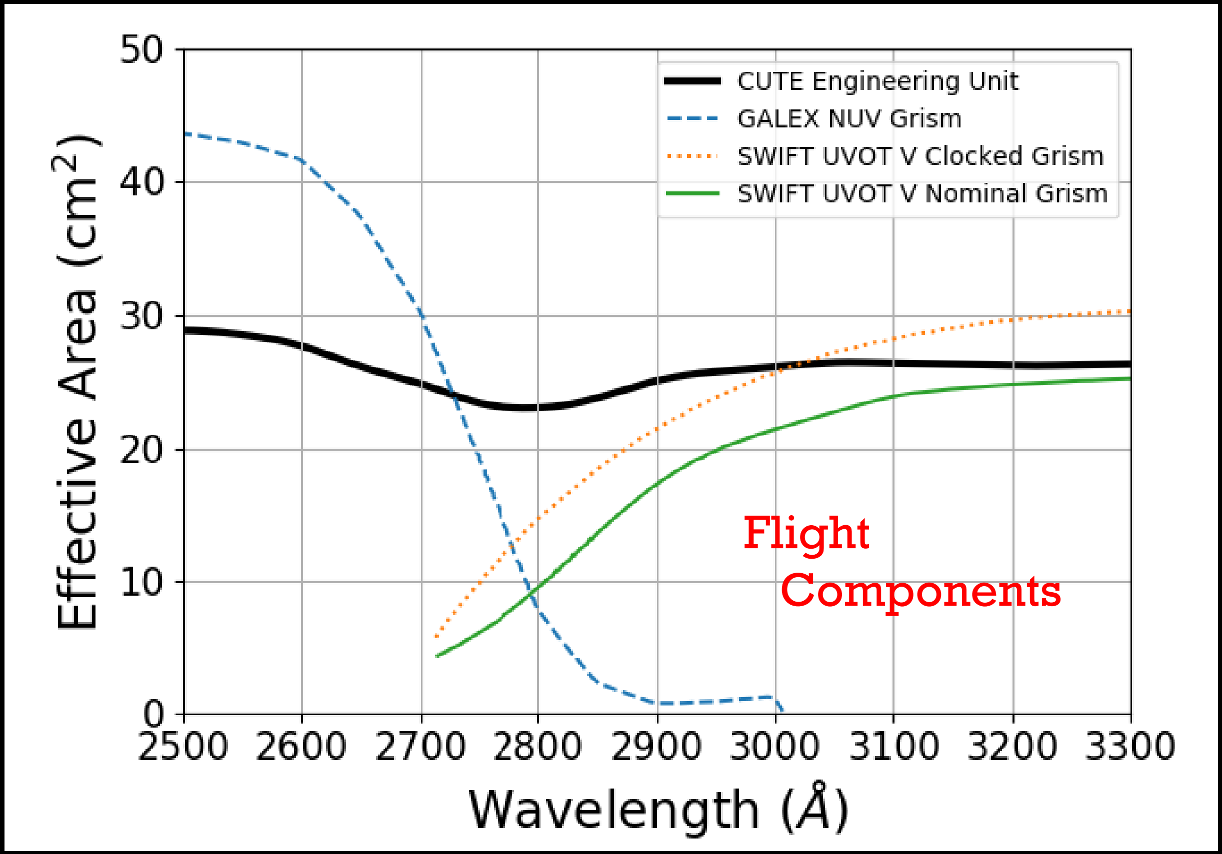


CUTE Measured Performance

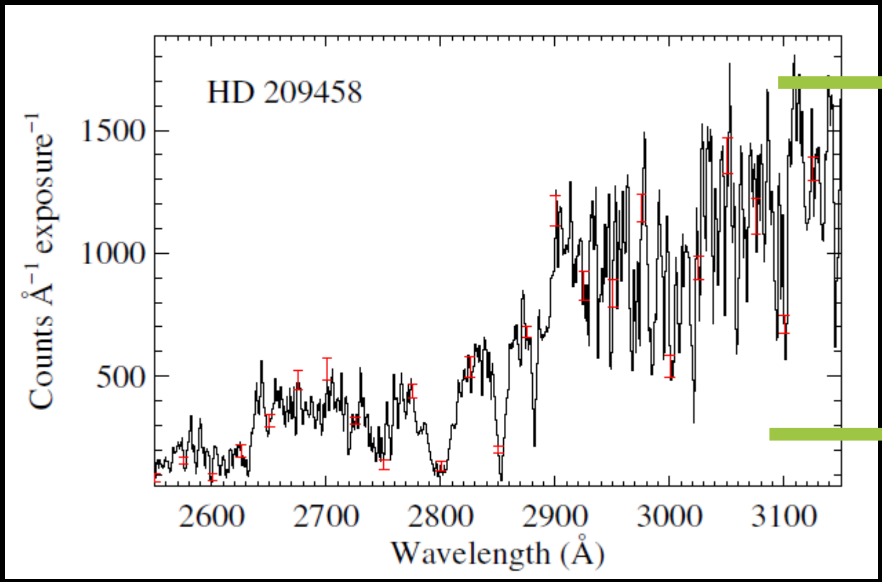


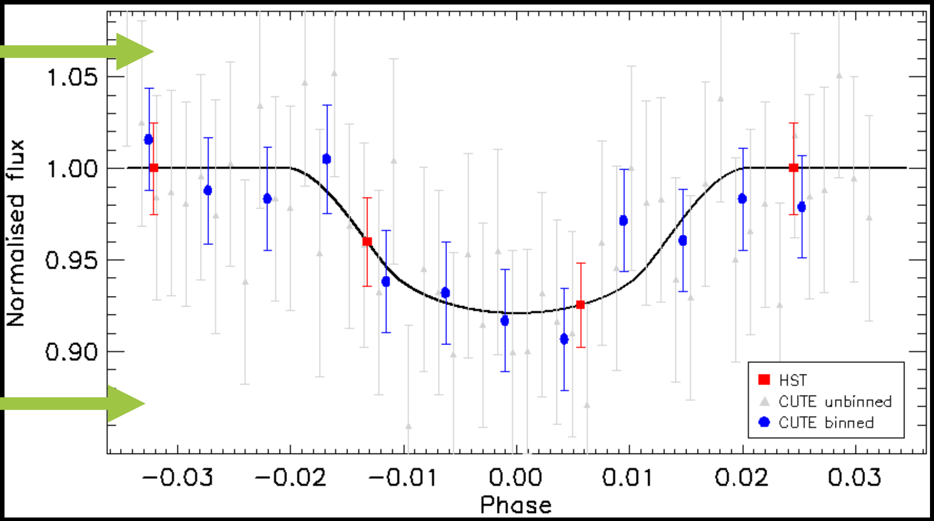
Instrument Sensitivity:

$A_{eff} = A_T\, R^5\, \varepsilon_{grat}\, QE_D =$ **20-30 cm^2**

R ≈ **2000**

CUTE Predicted Science Data



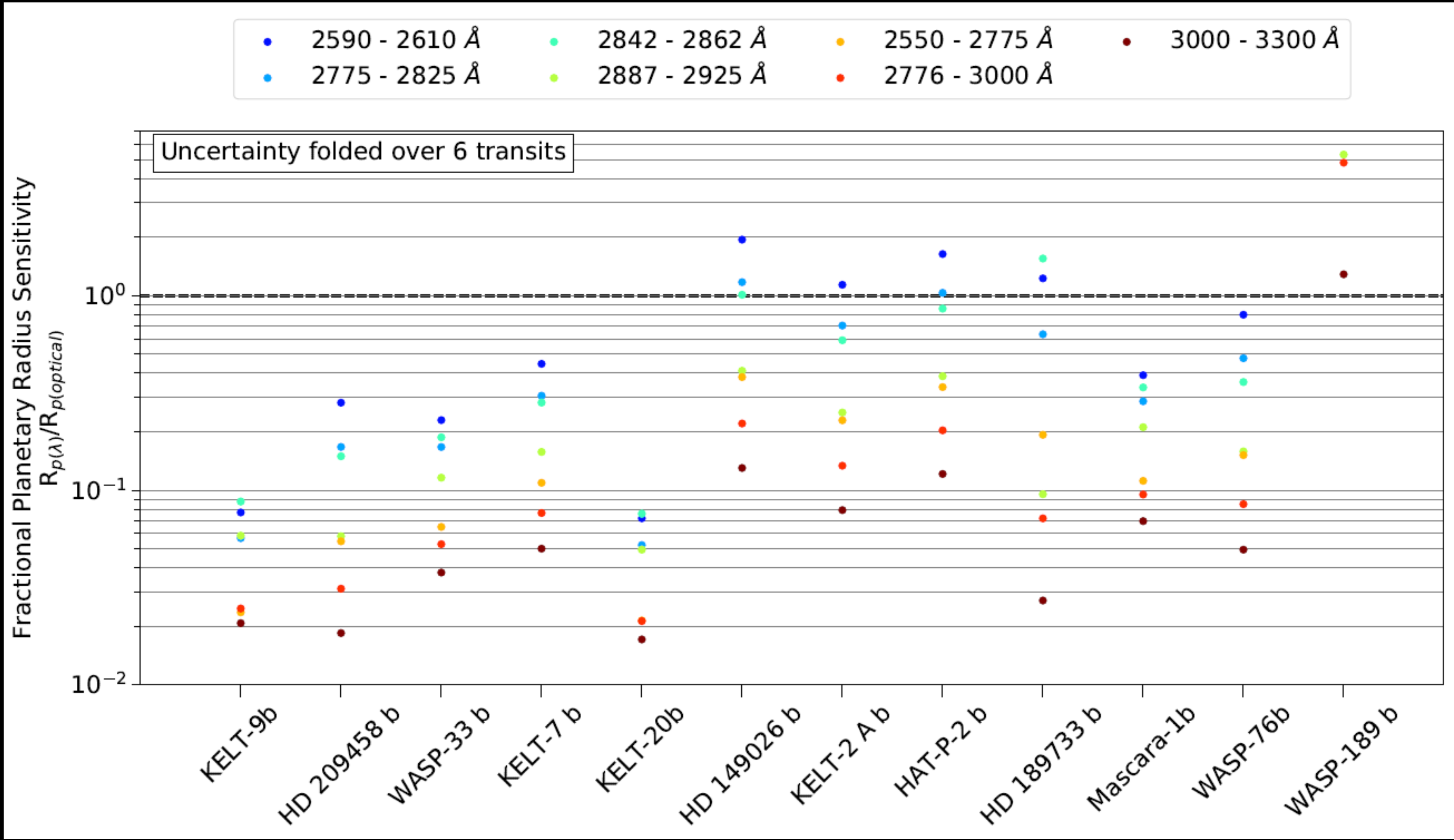


CUTE will achieve >3σ detections of transits as low as 0.1% depth for the brightest targets. Transit depths < 1% for all baseline targets with 5+ lightcurves per target.

Continuum transit sensitivity to 0.7% depth for median target over 1 transit

= Capable of detecting geometric transit and atmospheric transit

CUTE Predicted Science Data



= Capable of detecting geometric transit and atmospheric transit

Egan et al. (2020)

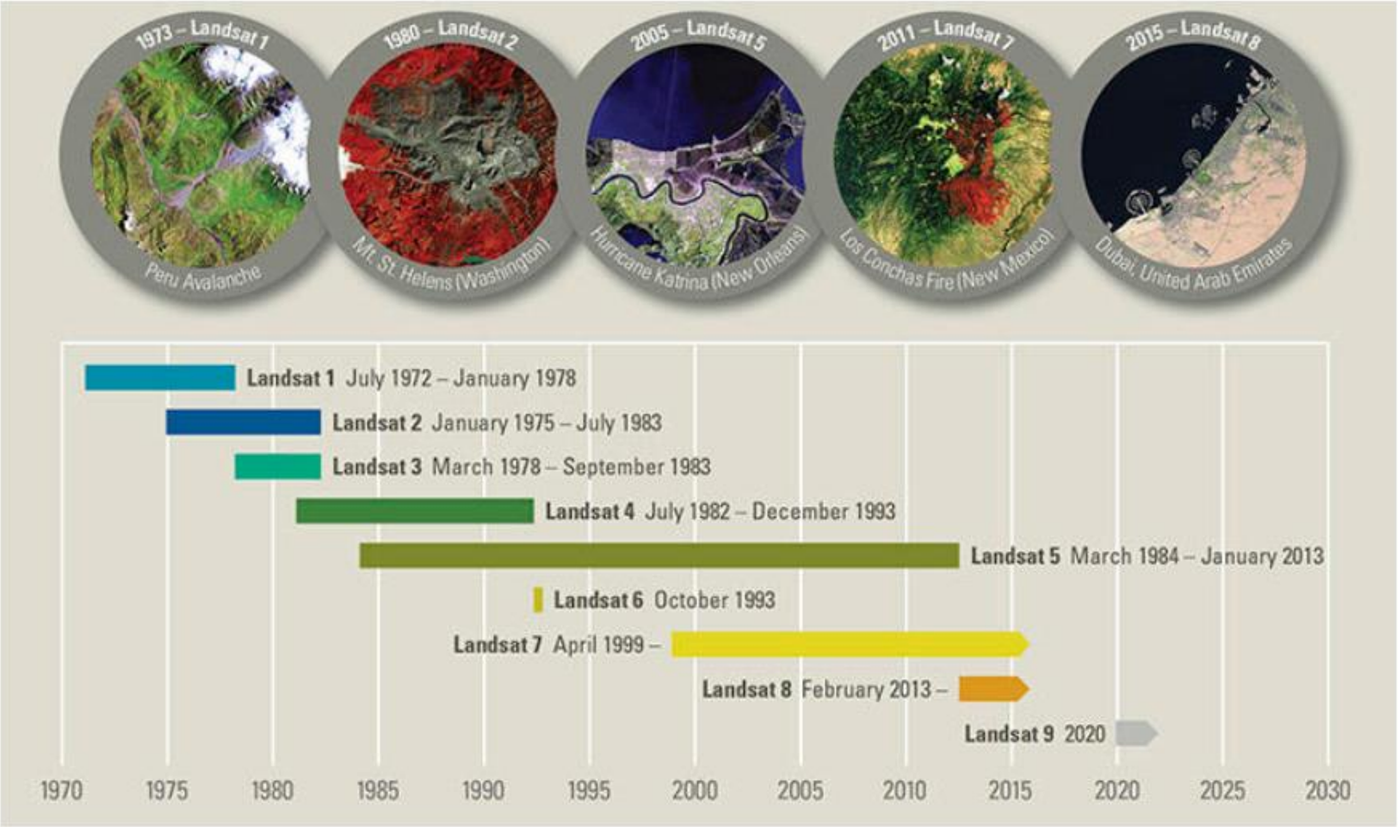
CUTE Status

When will the Landsat 9 satellite be launched?

Landsat 9—a partnership between the USGS and NASA—has a launch readiness date of December 2020.

Landsat 9 will be launched from Space Launch Complex 3E at Vandenberg Air Force Base in California and will be delivered into orbit by a United Launch Alliance Atlas V 401 launch vehicle.

Learn more: Landsat 9 Mission



CUTE

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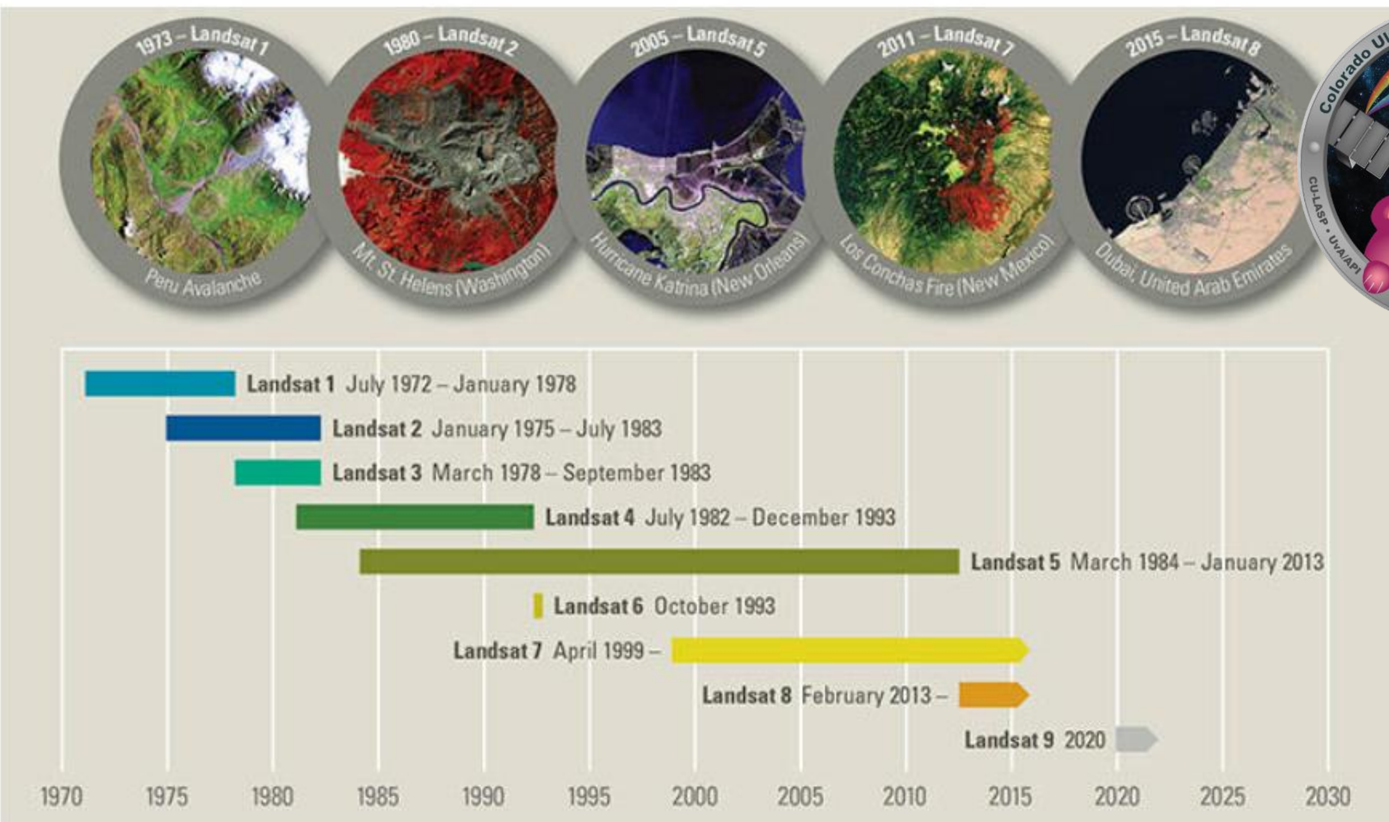
Learn more: [Landsat 9 Mission]



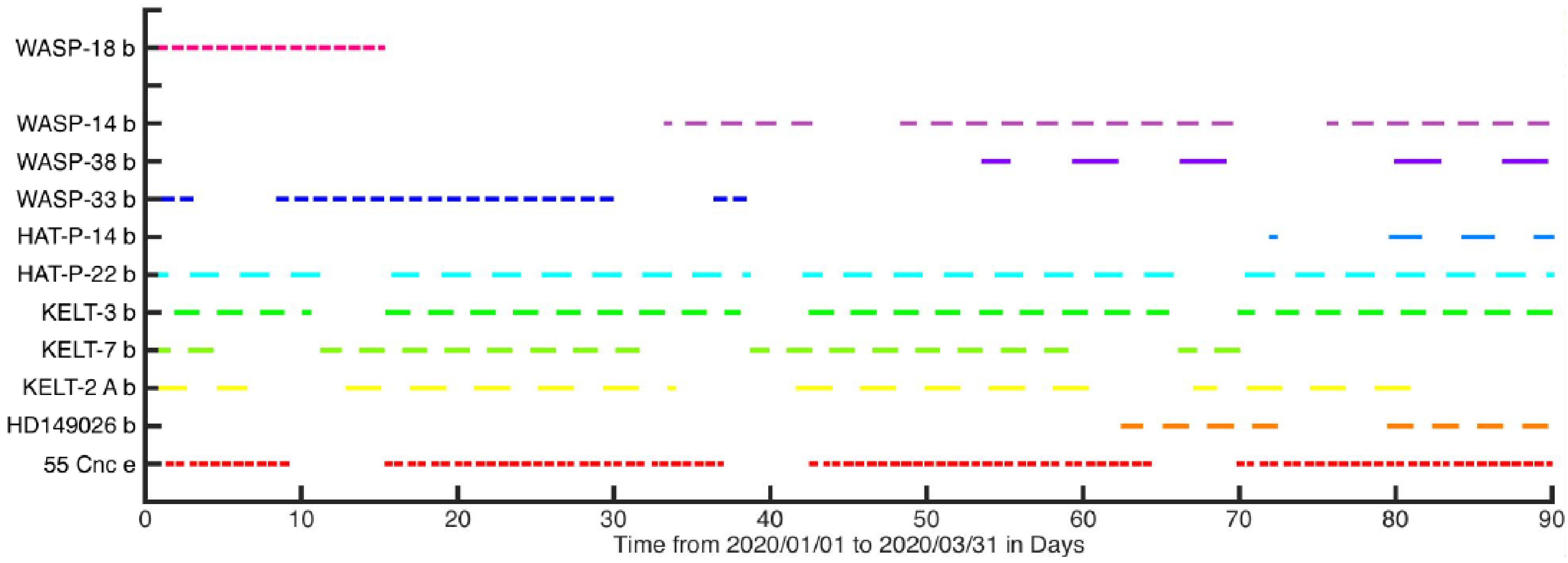
CUTE Status

- Proposed ROSES D.3 APRA - March 2016
- Selected February 2017, funded July 2017
- Science Team face-to-face meetings:
  Oct 2017, Nov 2018, Oct 2019, (Dec 2020)
- Assembly, test, calibration: almost complete
- Environmental Testing: April/May 2021
- Launch Late Q3-2021
  - 8 Month Baseline mission:
  - 12 exoplanetary systems, 6-10 transits each
  - 12 – 20 additional systems in 12 month extended mission

@CuteCubeSat

END

CUTE Example Target Visibility List



PI – France